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Adaptive Reactions of Cardiovascular System of Boys with Different Level of Sexual Maturity to Physical Exercise.

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ABSTRACT

Graduated physical exercise with the moderate power (50% of PWC_{170}) induces marked change in such cardiovascular system indices as stroke volume and cardiac output, heart rate in boys with the age of 11-16 years. The nature of reactions of the boys' cardiovascular systems rapid adaptation to physical exercise during adolescence period of ontogenesis depends on the level of their sexual maturity. The boys with the 1st and the 2nd grades of sexual maturity demonstrate the reactions to exercise with the highest growth of heart rate, while the highest growth of cardiac output is typical for the boys with the 3-5th grades of sexual maturity. It was revealed that for the boys with the 3-4th sexual maturity stages the reactions to physical activity were expressed in the maximum values of stroke volume and cardiac output and the recovery period for the investigated parameters was rather extended. At this stage of the boys' development the recovery of cardiac output to the level at rest has a non-linear nature, there can be observed a "negative phase" in the heart rate recovery which can be considered as a symptom of excessive response, unfavorable cardiovascular system reaction to physical exercise.

Keywords: adaptive reactions, cardiovascular system, stroke volume, cardiac output, heart rate, stages of sexual maturity, physical exercise.

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INTRODUCTION

The efficiency of education and guidance of schoolchildren to a large extent is conditioned by the state of their physical development and physical fitness. The cardiovascular system (CVS) which limits development of adaptive body reactions as well as the state of children's health is one of the systems ensuring adaptation of a maturating body to the effects of environmental factors, inclusive to the influence of physical exercise. It is well-known that during the adolescence period of ontogenesis which is specific due to a biological factor, i.e. the sexual development process, a heterochronic development of the body vital systems is being observed. It is exactly the adolescence period when the CVS overcomes considerable structural and functional changes, activity of the sympatic-adrenal and the endocrine systems grows, "the level of health" of schoolchildren is being formed [1,2]. In this period functioning of physiological systems is characterized by tension and has increased requirements to the CVS as a body vital system both at rest and at time of physical activity [1,3].

It's worth noting that the influence of various types of physical activity on the CVS of children and teenagers is considerably thoroughly studied under the conditions of physical culture schools, training and competition processes [3]. While rapid adaptation of the CVS of the teenagers with different level of sexual maturity to physical activities under the conditions of a general education school was investigated insufficiently.

In the meantime study of the mechanisms of development of the systems of a growing body gains specific significance at present since various environmental factors (i.e. increase of mental workload accompanied by relatively low motion activity, growth of psychophysiological effects intensity) have ever-increasing influence on a child's body. Specificity of the adolescence development period which is expressed in the marked individual differences in the time and rate of sexual maturation [1] conditions the necessity to perform differentiated studies of the teenagers depending on the stages of their sexual maturation.

All of the above determined the importance and the objective of our investigations.

Objective of investigation

Study of the peculiarities of the adaptive reactions of the cardiovascular system of male teenagers to a graduated physical exercise depending on the state of their sexual maturation.

SUBJECT AND METHODS OF INVESTIGATION

The investigation involved 180 boys in the age from 11 to 16 years who were the students of a general education school in Kazan city. The assessment was performed at the beginning of an academic year (in October) in the same days of the week and at the same daytime (the first half of the day).

The analysis of the functional state of the CVS was accomplished by a method of tetrapolar thoracic impedance plethysmography with the use of an impedance plethysmograph RPG-2-02 and an automated cardiopulmonary system (AD-03M). During investigations such indices as heart rate (HR), stroke volume (SV) and cardiac output (CO) were measured. The sexual maturation of teenagers was assessed with the use of J.Tanner scale. Physical working capacity was determined by means of PWC_{170} test. A graduated exercise on a cycle ergometer with the power of 50% of the individually determined PWC_{170} was used as a functional test. Statistical processing of the obtained results was made by means of parametric and non-parametric analysis methods, besides a correlation analysis of intrasystem and intersystem relations between the investigated indices was carried out. The standard values of Student's test were used to evaluate statistical significance of differences.

RESULTS OF INVESTIGATION AND DISCUSSION

According to our records an age-specific formation of hemodynamic indices of the CVS in male teenagers has a heterochronic nature and depends on the stage of their sexual maturation. The analysis of the results of investigation showed that the HR dynamics has an undulating nature. The most significant decrease of the HR can be observed in the boys within the period between the 1st and the 2nd stages of sexual

maturation (SSM) (by 10.5%; p<0.05). In the course of transition from the 2nd to the 3rd stage there can be observed the HR increase by 4.0% (p<0.05) which is in conflict with the age-specific trend in change of this index and is conditioned by changes in the endocrine system of the teenagers' body [7]. In the course of transition from the 4th to the 5th SSM there can be observed a repeated HR decrease by 8.7% (p<0.05). The boys at the 5th SSM have the value of HR which approximates to the adult level (Table1).

Table 1: Heart rate dynamics (BPM) at rest and after graduated physical exercise in boys with different stages of sexual maturation (M±m)

SSM	At rest	Period of recovery			
		1 min	3 min	5 min	7 min
1	82.6±0.7	102.2±1.4*	89.8±1.3*	83.1±2.4	81.8±1.4
2	74.1 ±0.9^{x}	94.8± 1.8*	88.6±1.1*	77.4±2.2	75.5±1.5
3	79.0 ± 1.0^{x}	92.2± 1.1*	72.2±1.1*	86.9±1.2*	80.7±1.6
4	77.9± 1.1	89.8±1.2*	70.3±1.0*	85.1±1.1*	78.7±1.7
5	70.5 ± 0.7^{x}	77.1±1.1*	72.5±2.1	71.9±1.9	71.2±1.6

Remark: ^{x} – difference as compared to the previous age group is statistically significant (p < 0.05)
* - difference as compared to the state of rest is statistically significant (p < 0.05).

Study of the cardiac output indices in male teenagers allowed establishing that the most significant increase of CD and CO could be observed at the 3rd SSM, i.e. during the intensive puberty period. The teenagers at the 4th SSM demonstrated the maximum values of cardiac output. By reaching the 5th SSM the stroke volume remains at the level which has been achieved earlier however the CO goes somewhat lower. The growth of CD within the period from the 1st to the 5th SSM makes 69.8% (p<0.05) at the average, the growth of CO makes 42.2% (p<0.05). Less intensive growth of CO can be explained by the considerable HR decrease at the boys' completion stage of puberty. Therefore the most considerable age-specific change of the hemodynamic indices can be observed within the intensive puberty period (from the 3rd to the 4th SSM). As far as the puberty processes go to an end (the 5th SSM) the CVS indices tend to stabilize at the level close to the definitive one (see Tables 2,3).

Table 2: Stroke volume dynamics (ml) at rest and after graduated physical exercise in boys with different stages of sexual maturation (M±m)

SSM	At rest	Period of recovery			
		1 min	3 min	5 min	7 min
1	42.9 ± 0.9	49.0±2.1*	47.9±1.2*	45.3±1.9	43.1±1.8
2	45.5 ± 0.7	51.5±2.2*	50.6±1.7*	47.2±1.8	46.7±1.9
3	61.9± 0.8 ^{x}	81.3±3.1*	80.2±2.5*	78.5±2.3*	64.1±1.4
4	74.0 ± 0.8^{x}	98.7±3.3*	89.1±2.3*	82.5±2.0*	73.0±1.7
5	72.5 ± 0.9	88.5±2.1*	75.7±1.5	74.4±1.2	72.8±1.1

Remark: ^{x} – difference as compared to the previous age group is statistically significant (p < 0.05)
* - difference as compared to the state of rest is statistically significant (p < 0.05).

Table 3: Cardiac output dynamics (l) at rest and after graduated physical exercise in boys with different stages of sexual maturation (M±m)

SSM	At rest	Period of recovery			
		1 min	3 min	5 min	7 min
1	3.6 ± 0.2	4.9±0.4*	4.4±0.2*	3.8±0.3	3.5±0.3
2	3. 5 ± 0.1	4.9±0.5*	4.5±0.4*	3.7±0.5	3.5±0.2
3	4.9 ± 0.1^{x}	7.4±0.6*	5.8±0.3*	6.8±0.4*	5.2±0.4
4	5. 8 ± 0. 2 ^{x}	8.8±0.7*	6.3±0.6	7.0±0.4*	5.7±0.5
5	5.4± 0.10	6.8±0.3*	5.5±0.5	5.3±0.4	5.2±0.2

Remark: ^{x} – difference as compared to the previous age group is statistically significant (p < 0.05)
* - difference as compared to the state of rest is statistically significant (p < 0.05).

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The results of investigation of the boys with different levels of sexual maturity were used for the correlation analysis between the indices of physical development (body length, body weight, body surface area, physical working capacity) and the CVS indices (HR, SV, CO). The stronger the relationship between the characteristics the higher the value of "r" coefficient which varies from -1 to +1. The analysis of correlation relationships showed that it could be characterized by dynamic nature and changed both depending on the level of the boys' sexual maturity and under the influence of graduated physical exercise. The teenagers with the 1st and 2nd SSM demonstrated stable relationship between the HR, the anthropometric parameters and the physical working capacity (r=+0.75 and +0.90 correspondingly). It's natural that during the following sexual maturation stages no strong dependency between the physical development indices and the HR value is observed, a stable relationship between these indices and SV occurs instead (r=+0.68 and +0.87 correspondingly). The boys with the 5th SSM demonstrate negative relationship between the HR and the physical working capacity (r=-0.65). Therefore the high heart rate at rest is a factor constricting physical working capacity of the teenagers. The study of correlation interrelationships between the CVS parameters showed that the teenagers with the 1st and 2nd SSM had strong relation between the HR and the CO (r=+0.72). The following stages of sexual maturation (3-5 SSM) to the contrary demonstrate strengthening of relationship between the SV and the CO (r=+0.78), a negative relationship between the HR and the SV can be observed at the 5th SSM (r=-0.72). The results obtained by us confirm weakening influence of a chronotropic component and strengthening influence of an inotropic one with the increase of age [1,7].

We evaluated the nature of rapid adaptation of the boys' CVS to the graduated physical exercise (50% of PWC_{170}) by shifts in the values of HR, stroke volume and CO during the first minute of the recovery period as well as by dynamics of the said indices during the third, fifth and seventh minutes of recovery. It was supposed that the shift under the influence of exercise reflected the CVS responsiveness. The length of the period of the indices return to the background level was also taken into consideration.

According to our data (see Tables 1-3, Figure 1) all of the examined boys demonstrated considerable growth of the hemodynamic indices under the influence of physical exercise, but the level of growth was different for various stages of sexual maturation.

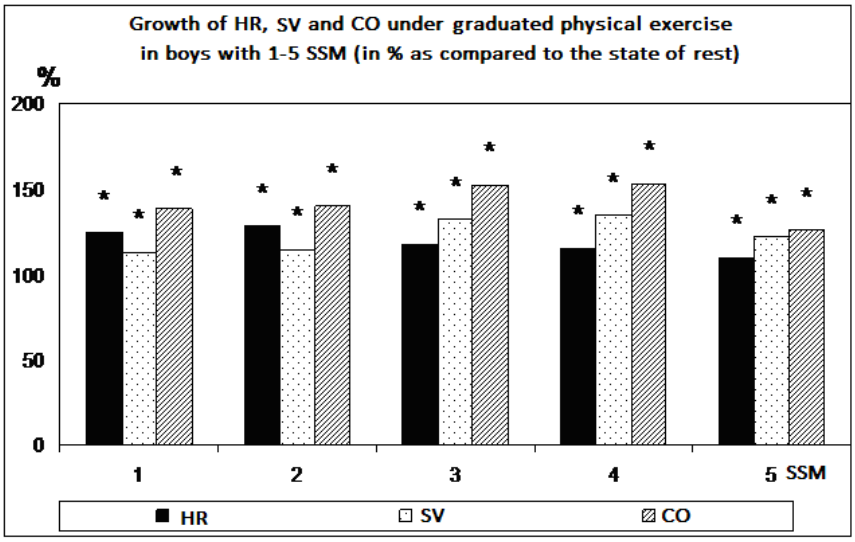

Figure 1: Growth of heart rate (BPM), stroke volume (ml) and cardiac output (l) under graduated physical exercise in boys with 1-5 SSM (in % as compared to the state of rest).

Remark: * - difference with the state at rest has statistical significance ($p < 0.05$).

A marked chronotropic effect of the CVS as a response to the applied functional test can be observed in the boys with the 1st and the 2nd SSM (see Table 1, Figure 1). The HR growth in the stated groups of schoolchildren makes 24.8-25.0 % on the average ($p<0.05$). In the course of sexual maturation the chronotropic effect as a response to physical exercise gets lower and the teenagers with the 5th SSM demonstrate as much as 9.9% ($p<0.05$) of the HR growth due to physical load. The literature sources state that the lower HR growth due to moderate physical exercise can be observed in children who have more extensive

functional capabilities and more advance CVS control mechanisms [8]. To the contrary the inotropic reactions of the CVS of teenagers grow stronger with advancing age (see Tables 2, 3, Figure 1). The most significant SV growth was observed in the teenagers at the 3rd and 4th SSM and made 32.6 % and 31.8% correspondingly ($p<0.05$). The lowest SV growth was recorded for the boys with the 1st and the 2nd SSM (13.1% and 13.8% correspondingly; $p<0.05$). The boys with the 5th SSM demonstrate more intensive inotropic response as compared to the boys with the 1st and the 2nd SSM but a little bit lower than the boys with the 3rd and the 4th SSM. The CO growth as a response to physical exercise increases continually from the 1st to the 4th SSM, where it makes 52.9% ($p<0.05$) on the average and decreases in the 5th SSM making just 26.0% (see Table 3, Figure1).

Since the CO dynamics reflects correlation between the chronotropic and the inotropic heart responses it would be reasonable to establish the role of these cardiac function components in maintaining the growth of CO as a response to physical exercise. The carried-out analysis showed that the boys with the 1st and the 2nd SSM have prevalent chronotropic response accompanied by the minimum inotropic effect. Rapid CVS adaptation is possible mainly due to the HR increase. In the course of sexual maturation starting from the 3rd SSM the role of SV in maintenance of the CO becomes more significant. The teenagers with the 5th SSM demonstrate balanced correlation between the chronotropic and inotropic heart reaction and growth of the role of SV in maintaining of the CO.

Study of the CVS indices dynamics under the influence of moderate physical exercise showed that the teenagers with various stages of sexual maturity had differences in the nature and duration of recovery of the investigated parameters to the initial level.

The boys with the 3rd and the 4th SSM demonstrate non-linear nature of the CO recovery to the state at rest. The HR recovery goes through a “negative phase” which is characterized by decrease of the value of this index below the initial level. It is considered to be a symptom of excessive reaction, unfavorable response of the CVS to physical exercise.

Average duration of the CVS indices recovery to the level at rest for the boys with the 1st and the 2nd SSM makes 4.3 minutes, the teenagers with the 3rd and the 4th SSM demonstrate the maximum duration of recovery of all of the studied parameters. Average time for the HR recovery in the mentioned groups makes 5.5 and 6.1 minutes, for the SV recovery – 6.0 and 6.5 minutes, for the CO recovery – 5.8 and 6.3 minutes correspondingly. The shortest recovery period for the CVS indices was recorded for the boys with the 5th SSM. The time of recovery makes 3.5 minutes on the average. It’s worth noting that the HR recovers to the initial level faster then the cardiac output in all of the investigated groups. The recovery duration makes 4.4 and 5.3 minutes on the average correspondingly.

The correlation analysis of intrasystem relations between the boys’ CVS indices allowed detecting a change in the stability of all existing relations between the studied parameters after the graduated physical exercise. Adaptation of the CVS of the boys with the 1st and the 2nd SSM is accompanied by considerable strengthening of the HR-CO relation. The correlation coefficient increases from +0.68 to +0.82, no increase of the SV-CO correlation relation strength as compared to the state at rest was registered. The observed tendency confirms the HR priority in the CO maintenance for the boys at the first stage of sexual maturation. To the contrary the boys with the 3rd and the 4th SSM demonstrate weakening of the range of the existing relations of the CVS indices after physical exercise as compared to the initial level which is considered as unfavorable reaction reflecting some unbalance between the CVS parts which is observed at time of the functional test application. All of the above evidences the intense functioning of the CVS in the specified age groups as its was mentioned earlier [1]. At the same time strengthening of the SV-CO relation can be observed (from $r=+0.78$ to $r=+0.93$) which is indicative of the leading role of the SV in maintaining of the CO in the boys with the 3rd and the 4th SSM. At the final phase of sexual maturation the teenagers with the 5th SSM also demonstrate strengthening of relation between the cardiac output indices (SV-CO). This is considered to be a positive phenomenon which is indicative of high tolerability of exercise, favorable reaction of the CVS to the functional test and reflects interdependent balanced functioning of the CVS parts.

The comparative analysis of the reactions of rapid adaptation of the boys belonging to the same age group but having different stages of sexual maturation showed that the CVS responsiveness as well as the nature of adaptive reactions is determined mainly by the level of sexual maturity.

Thus the averaged value of the correlation coefficient of the CVS indices depending on the sexual maturation stage varies from +0.80 to +0.93 for different parameters, while the relation between the age groups is less strong despite of its statistical significance. The correlation coefficient varies within the range from +0.61 to +0.72 and is characterized by maximum stability for the SV-CO interrelation (r =+0.84).

Findings

- The most significant change of the hemodynamic indices can be observed during the intensive puberty period of the boys (the 3rd and the 4th stages of sexual maturation). As far as the puberty processes approach towards their completion (the 5th SSM) the CVS indices level becomes stable and close to the definitive one.
- For the boys with the 1st and the 2nd stages of sexual maturation the graduated moderate physical exercise induces the maximum growth of the heart rate while the boys with the 3-5 stages demonstrate more intensive growth of the cardiac output.
- The boys with the 3rd and the 4th stages of sexual maturation showed the maximum reactions of stroke volume, cardiac output to the physical exercise as well as a prolonged period of recovery of the studied parameters to the initial level. This period of development is characterized by presence of a "negative phase" in the heart rate recovery process in the course of the cardiac output recovery to the state at rest which is considered to be a symptom of excessive response, unfavorable reaction of the cardiovascular system to the physical exercise.

CONCLUSION

The analysis of adaptive reactions of the CVS of boys with the age of 11-16 years to the physical exercise showed that the nature of reactions depended on the sexual maturity level. The 3rd and the 4th stages of sexual maturation are a critical period of the boys' cardiovascular system formation. The determined specific character of the rapid CVS adaptation reactions should be taken into consideration at time of planning physical exercise for the boys in the period of sexual maturation.

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